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HEIGHT - DIAMETER PREDICTIVE EQUATIONS FOR RUBBER (*HEVEA BRASILLIENSIS-A. JUSS- MUELL*) PLANTATION, CHOBA, PORT HARCOURT, NIGERIA

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ABSTRACT
The importance of calibrating models on height-diameter relationship can never be over emphasized in predicting mean total height for trees when only diameter at breast height is measured traditionally. This study has evaluated a set of height-diameter models from twenty plots of Hevea brasilliensis plantation in Choba, Port Harcourt, Nigeria. Non linear techniques were used to develop the functional models with models coefficients derived from 198 sampled standing trees. The predictive models gave a good height - diameter relationship from all the sampled plots in the plantation with coefficients of determination (R^2) of strong relationships ranging between 0.62 - 0.98. Many of the resulting models and curves agreed with silvicultural expectation of sigmoidal growth functions; and can provide dependable cum flexible options of predicting heights, given dbh for many plantation species in Nigeria.

Keywords: height-diameter equations, allometric models, predictive equations, sigmoidal curve

INTRODUCTION
Among pertinent tree characteristics for quantitative tree measurements and reasonable prediction are diameter at breast (dbh) and height. They proffer logistic data for modeling and futuristic prediction for sustainable forest management. Diameter is one of the most frequently measured mensurational variables in forestry particularly when sustainable forestry is focused. Significantly, diameter measurements has been noted to be made along a tree, branch or log; and these measurements can either consist of the bark, normally refered to as diameter outside bark (dob) or with exclusion of the bark, termed diameter inside bark (dib). The most common diameter measurement made on standing trees is taken at breast height and with inclusion of bark , this diameter is referred to as diameter at breast height (dbh). The word “breast height” is defined as 1.3m or 4.5 feet above the ground level or estimated point of germination. This connotes a standard location of diameter measurements on standing trees which allows for meaningful comparisons among measurement. Conversely, height measurement is not as frequently measured though inevitably significant in various quantitative estimation following the intricacy of time, availability of modern equipments, possibility of observer’s errors and visual impediments. Thus, few foresters seem to sparsely engage in continous tree height measurement. Importantly, height-diameter equations had been discovered for predicting height for a given diameter at breast height and species. These height-diameter equations are primarily useful in estimating others tree parameters that variously important in forest growth modeling and many sustainable forest management options(e.g., Van Deusen and Biging 1985, Larsen and Hann 1987, Larsen 1994). Numerous of these models have been developed and postulated to predict tree heights from diameter at breast height (dbh)(e.g. Meyer 1940,Monserud 1975, Ek et.al 1984, Parresol 1992). Lei Yuancai and Bernard Parresol (2001) however reported that many of these models

are limited and not a reflection of pertinent characteristics of models that would give height-diamter relationship curves with monotonic increment, inflection point and asymptote with a S-shaped which is significantly appropriate in describing realistic height-diameter relationship with many forest biological growth pattern. In accordance to Lei Yuancai and Bernard Parresol (2001) postulation, the curve of such functional models should be archetypal of a height cummulative growth curve, which begins at the origin value, and increases progressively to reach maximum growth at an inflection point and then gradually approaches an asymptotical value of sigmoidal curve (Fig.1).

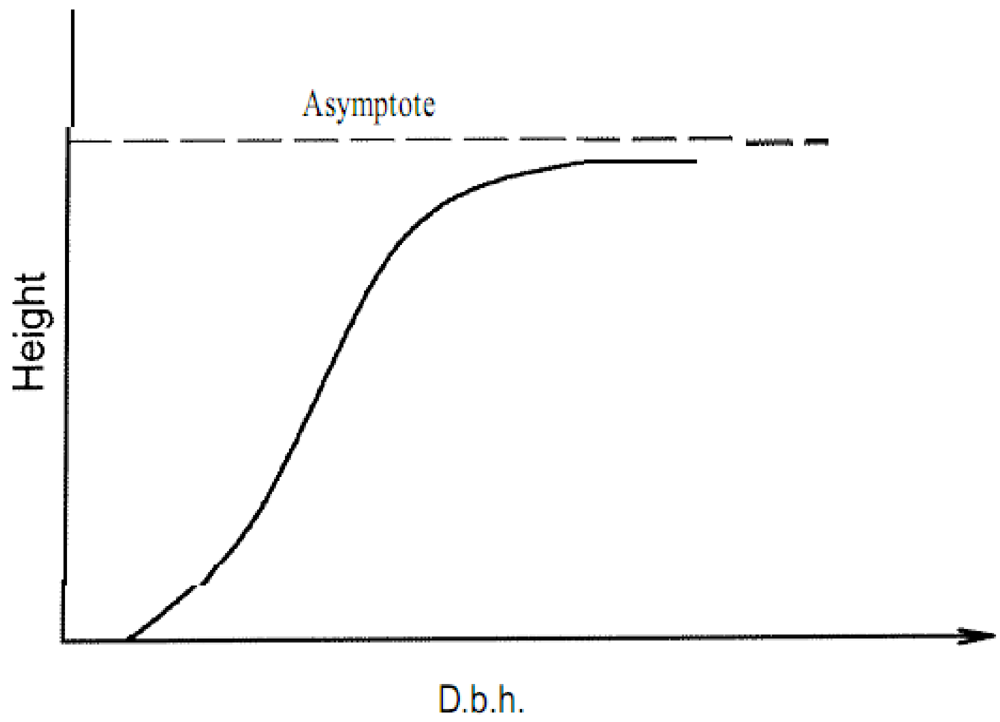


Figure 1 : Sigmoidal curve showing the relationship of height and diameter at breast height (dbh)

After critical examination of different flexible height-diameter models that can easily fit traditional dataset, Monserud's model was adopted for this study. Specifically, Monserud's (1975) model form is:

$$ht = bh + e^{(\beta o + \beta 1Db2)} \quad \text{..Equation 1}$$

Where ht is the total height (ft), bh is the breast height and the D is the diameter at breast height and β_1-β_2 are the parameters of of the function. Monserud's model enforces the contraint that as D approaches zero,*ht* approaches bh at 4.5ft which is diameter at breast height.

Many works and researches had been done in many parts of the world to show functional relationship using empirical model (Fang and Bailey 1998; Parresol 1992;Huang 1992); particularly of those involving sigmoidal curve of models of height and d.b.h., but conversely there is exceedingly paucity of literatures and studies done on height-diameter modeling on forest characteristics modelling in Nigeria and many sub-sahara. Therefore in this paper, we propose to develop height-diameter predictive equations for *Hevea brasilliensis* plantation in Choba, Port Harcourt, Nigeria employing Monserud's model.

METHODS

Numeric data for developing the empirical models were obtained from Twenty (20) systematically sampled plots of *Hevea brasilliensis* plantation in Choba, Port Harcourt, South- South region of Nigeria (6^o 54'E – 6^o 55'E, 4^o 53'- 4^o 54'N); as shown in Figure 2. A total of 198 standing trees were measured from the pure rubber stand of the sampled plots of dimension 20m x 50m (i.e. size 0.0ha). Growth characteristics such as height and diameter over bark at breast height (dbh) were measured for modeling and investigation of relationship between height and dbh. Arithmetic means of total height and dbh were carried out using SPSS statistical package programme. The total height is considered as dependent variable while dbh is considered as independent variable.

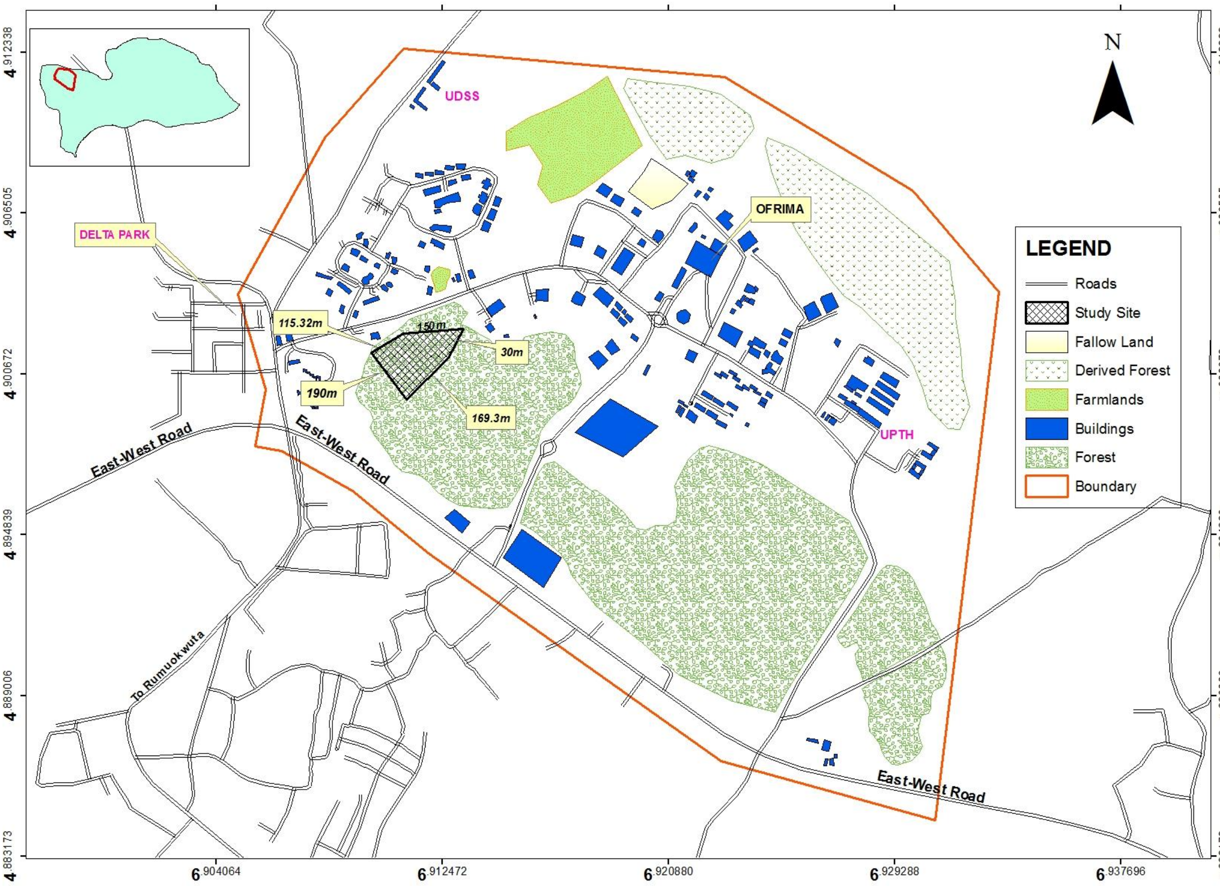


Figure2: Map of Abuja Park, University of Port showing the Study Site (Rubber Plantation)

The growth parameters in each plot were summarized by mean, standard deviation, minimum and maximum in Table 1.

The initial Monserud's model was transformed using natural logarithm and fit to the data using the equation:

$$lnY = \beta_o + \beta_1 D^{-0.02} \quad \text{……………………………………….Equation 2}$$

Such that $y = \beta o + \beta_1 \ln(D)$ ……………………………………………Equation 3

The procedures for modelling were critically evaluated based on graphical and numerical analysis of the residuals and values of two statistics: the Residual standard error or mean square error (MSE), which expresses the precision of the estimates; and the coefficient of determination (R^2), which shows the element of the entire variance by the model at p= 0.05 level of significance as a confidence level. The R^2 is mathematically expressed as:

$$R^2 = 1 - \left[\frac{SSR}{SSTO}\right] = 1 - \frac{\sum(Yj - \bar{Y}j)^2}{\sum(Yj - \hat{Y}j)^2} \text{ ………………………Equation 4}$$

Where SSR is the regression sum of squares and SSTO is the sum of squares total with $\hat{Y}j$ being the model estimate for jth estimate, $\bar{Y}$ is the sample mean and Yj is the jth observation

RESULTS AND DISCUSSION

Non linear (logarithm) equations of the form of Equation 1 were fitted to each height – diameter dataset in each of the plot. These equations were chosen following the order of Monserud's model that described perfect relationship between height and diameter of growth pattern . Fifteen plots produced a sigmoidal height while plots seven, seventeen, eighteen, nineteen and twenty produced concave- shaped curve which contradict the sigmoidal curve of growth functions. This trend is shown in Figure 1 where the prediction equations are plotted for each plot at ninety five percent confidence bounds with the data observations. The coefficient and fit statistics for the 20 plots are reported in Table 2 while the range each height–diameter curve shows the range of the fitted data set (Table 1).

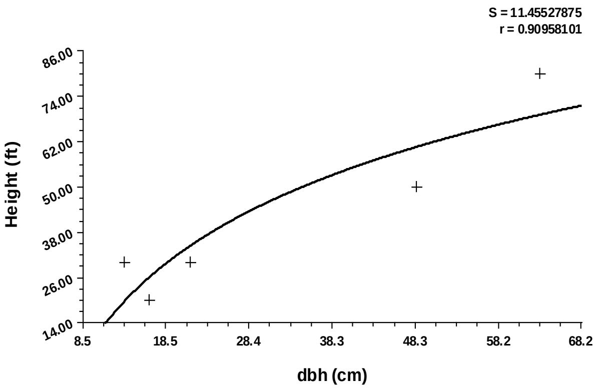
Plot 10 has one of the best regression fits, an R^2 of 0.98. Other equations with R^2 of 0.90 or greater include plot 1, plot 4, plot 6 and plot 14. Plots 2, 3, 5,7, 8, 13,15,16,17,18,19 and 20 have R^2 values less than 0.70; while plots 9,11 and 12 have R^2 have less than 0.2. Plot 6 has the smallest dataset on which the prediction equation was fitted; yet the relationship of height-diameter was significantly strong with R^2 value of 0.94. This trend corroborated the findings of Colbert *et.al* (2002) which reported a sigmoidal curve relationships in the height-diameter equations of some thirteen Midwestern bottomland hardwood species of riparian forests along major rivers in Missouri, Illinois and Iowa with significant high coefficient of determination (R^2). Adekunle (2007) conversely reported that there exist high negative correlation between dominant height and logarithm mean in a natural forest in Nigeria; thus making the findings of this study peculiarly applicable to plantation forests. However, the low relationship obtained in this study following the small values of coefficient of determination of the model in some three plots may be an indication of site quality deficiency or the need for silvicultural alternatives which may be further investigated for optimum and sustainable management of the plantation.

Table 1: Summary of diameter at breast height (dbh) height statistics for each plot of *Hevea brasilliensis*

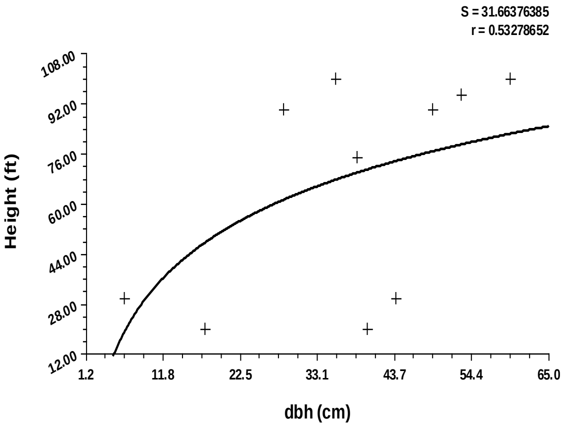
		Diameter at breast height (dbh/cm)				Height (ft)			
Plot number	n	Mean	SD	Min	Max	Mean	SD	Min	Max
Plot1	5	32.60	21.99	13.50	63.20	42.00	23.87	20	80
Plot2	10	37.25	16.17	6.50	59.70	65.00	35.28	20	20
Plot3	10	39.32	13.03	19.40	60.00	50.00	22.61	10	80
Plot4	5	32.28	16.74	15.10	52.00	51.60	28.99	20	75
Plot5	8	40.89	17.03	16.50	64.40	70.00	30.36	20	100
Plot6	4	46.65	21.80	19.80	64.40	82.50	24.66	55	110
Plot7	9	36.62	18.11	18.00	82.00	62.78	20.17	30	80
Plot8	6	39.38	26.56	15.70	84.60	70.00	21.91	40	100
Plot9	10	42.70	25.14	18.20	84.40	61.00	18.23	40	95
Plot10	9	58.49	26.08	18.00	80.80	70.56	17.04	40	90
Plot11	10	50.64	22.16	19.20	80.00	72.50	12.53	50	90
Plot12	11	41.10	15.68	24.20	80.50	78.64	30.75	35	120
Plot13	11	29.82	15.29	17.50	58.60	72.73	25.82	30	100
Plot14	16	30.78	15.99	17.20	78.80	67.50	26.14	30	140
Plot15	10	39.37	18.76	18.20	73.60	75.50	23.03	40	105
Plot16	10	30.89	12.09	16.10	54.20	56.00	27.46	10	100
Plot17	13	38.31	15.52	18.00	70.00	65.38	24.62	20	110
Plot18	14	30.91	8.89	17.50	50.30	72.14	24.08	40	105
Plot19	16	55.88	23.11	18.20	90.10	87.19	11.54	60	100
Plot20	7	41.19	15.23	15.50	54.00	93.57	14.92	75	110

Max, maximum; Min, Minimum; n, number of sampled trees per plot; SD, Standard Deviation.

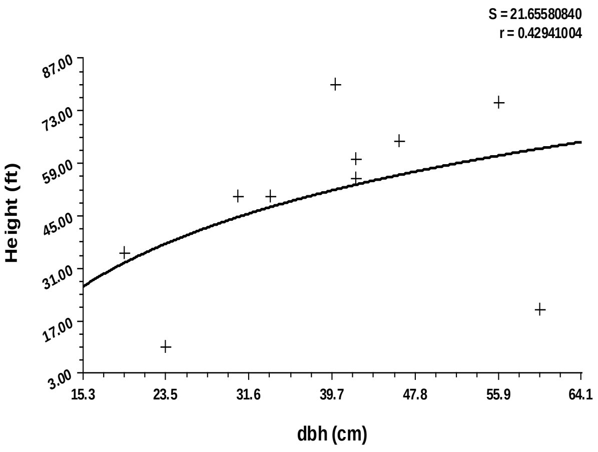
Plot1



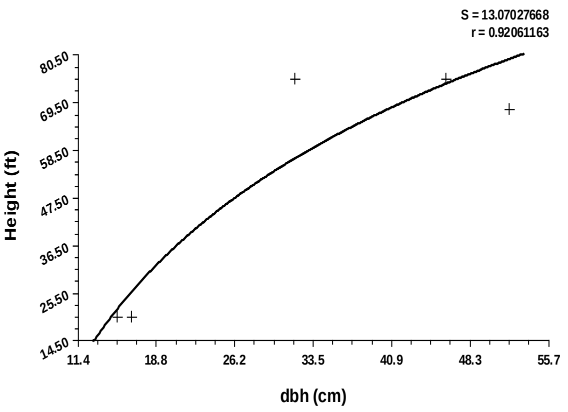
Plot 2



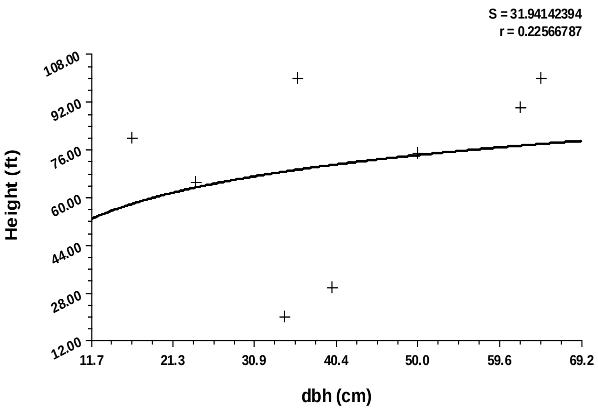
Plot 3



Plot 4



Plot 5



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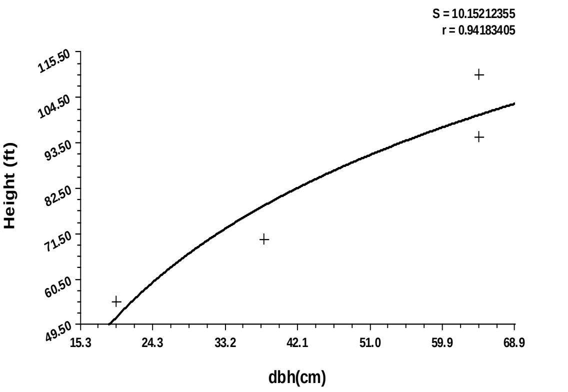
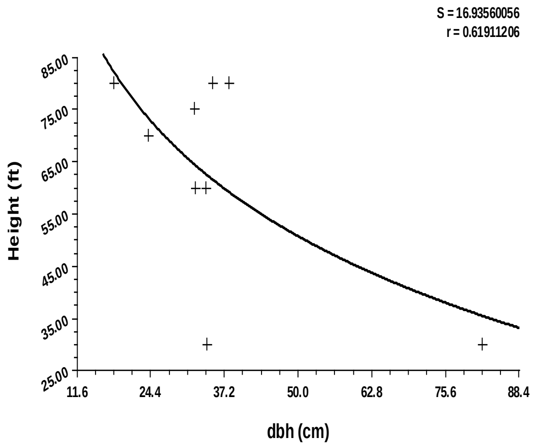
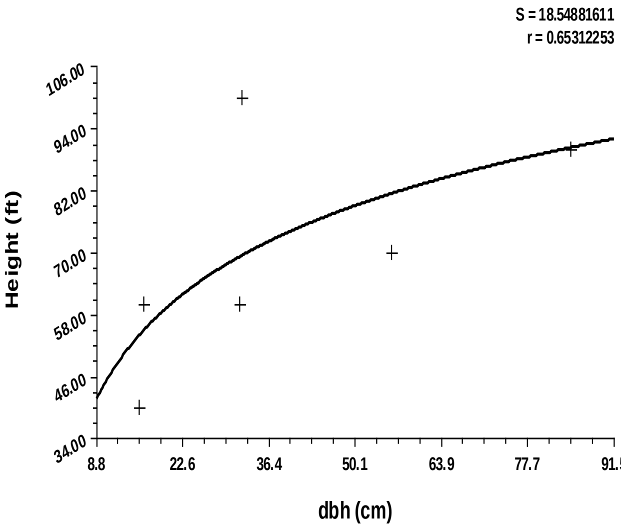


Plot 7

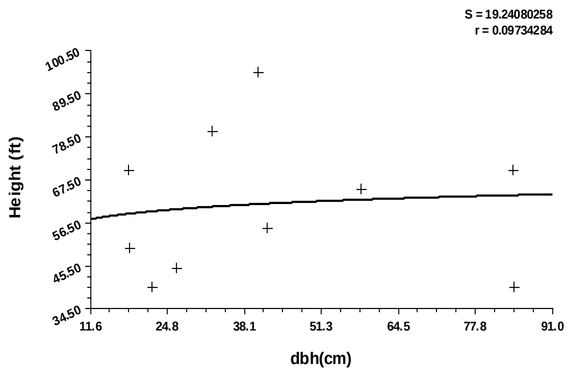
Plot 8

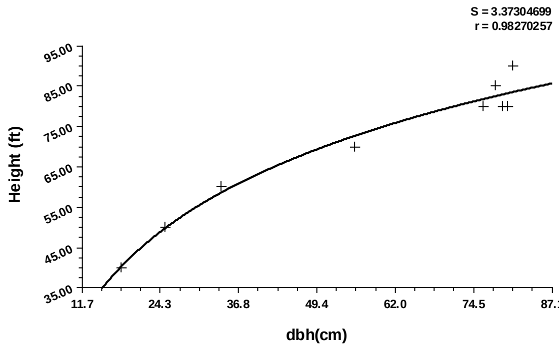




Plot 9

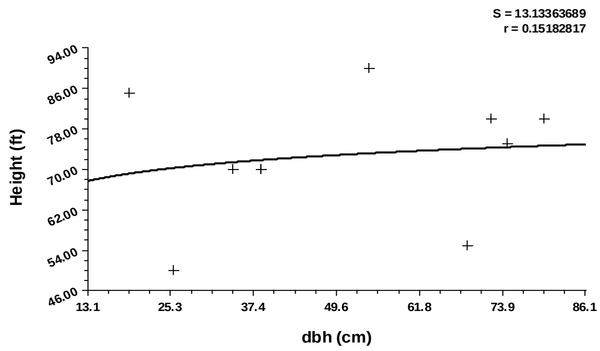
Plot 10

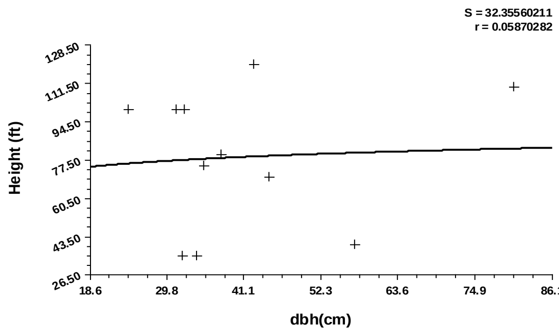




Plot11

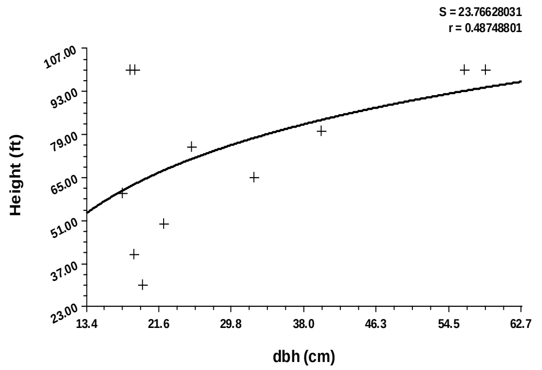
Plot 12

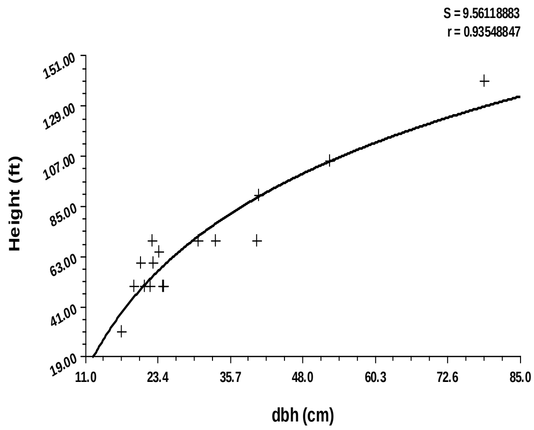




Plot 13

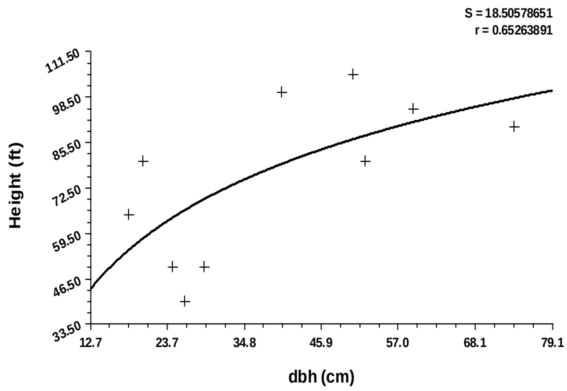
Plot 14

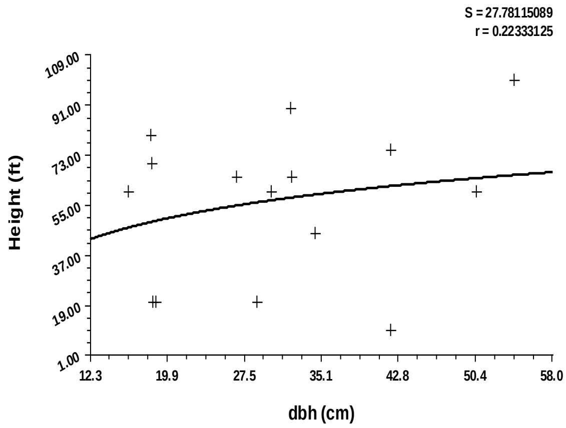




Plot 15

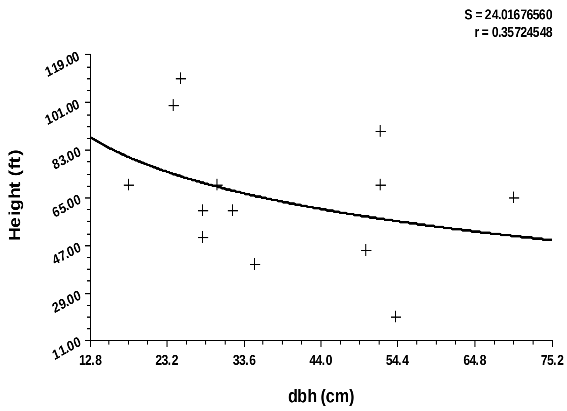
Plot 16

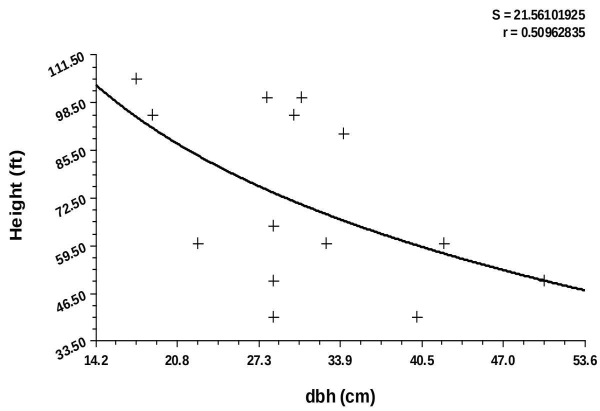




Plot 17

Plot 18





Plot19

Plot 20

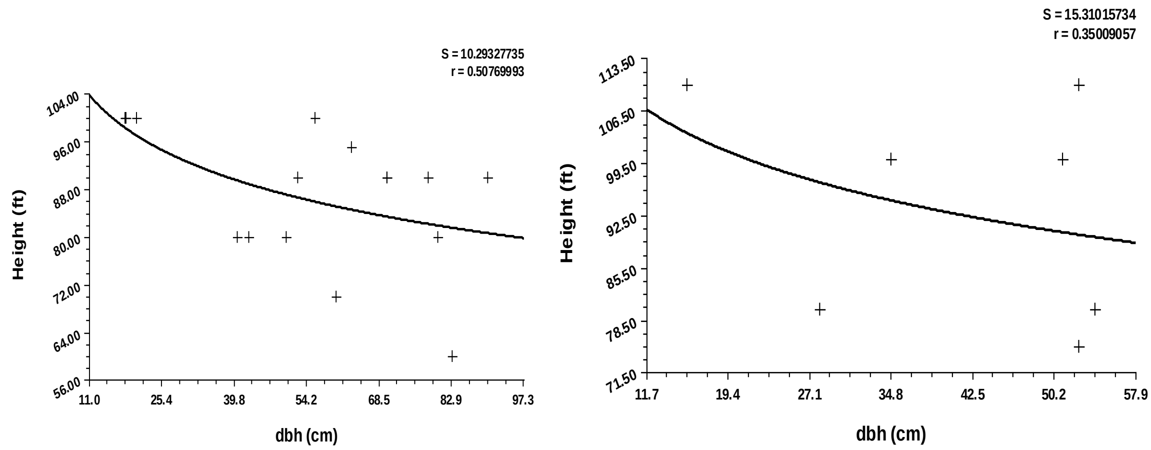


Figure 1: Height –diameter curves of *Hevea brasilliensis* with prediction models at 95% confidence limits plotted over observed data

Table2: Coefficients for the fitted models to predict height (ft) from dbh (cm) for each plot of *Hevea brasilliensis* plantation

Plot	n	βo	βo	SD	R^2
Plot1	5	-6.36 X10-^{3}	3.20	11.46	0.91
Plot2	10	-3.37 X10-^{3}	2.84	31.66	0.53
Plot3	10	-4.76 X10-^{3}	2.69	21.66	0.43
Plot4	5	-1.05 X10-^{3}	4.67	13.07	0.92
Plot5	8	1.66 X10-^{3}	1.47	31.94	0.23
Plot6	4	-7.26 X10-^{3}	4.15	10.51	0.94
Plot7	9	1.71 X10-^{3}	-3.07	16.94	0.62
Plot8	6	-4.95 X10-^{3}	2.15	18.55	0.65
Plot9	10	4.99 X10-^{3}	3.09	19.24	0.09
Plot10	9	-4.29 X10-^{3}	2.88	3.37	0.98
Plot11	10	5.77 X10-^{3}	3.86	13.13	0.15
Plot12	11	5.85 X10-^{3}	5.50	32.36	0.06
Plot13	11	-1.86 X10-^{3}	2.77	23.76	0.49
Plot14	16	-1.30 X10-^{3}	5.93	9.56	0.94
Plot15	10	-3.52 X10-^{3}	3.10	18.51	0.65
Plot16	10	3.87 X10-^{3}	1.55	27.78	0.22
Plot17	13	1.44 X10-^{3}	-2.19	24.01	0.36
Plot18	14	2.15 X10-^{3}	-4.22	21.56	0.51
Plot19	16	1.30 X10-^{3}	-1.10	10.29	0.51
Plot20	7	1.34 X10-^{3}	-1.11	15.31	0.35

CONCLUSION

The study has observed the relationship of height-diameter in allometric models of *Hevea brasilliensis* plantation that has not been explored in Nigeria. The method of modeling for many of the relationships obtained in this study produced height-diameter models that are consistent with biological expectation of sigmoidal curve; such that the models are flexible, easy to apply and manipulated for reasonable predictions and forecast of height and diameters in various aspects of inventory, modelling and other mensurational estimates involving volume estimation and stand characteristics. This procedure without doubt can be notably relevant to quantitative assessment of many plantations in the south-south region of Nigeria for reasonable decision making and future forecast.

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